High Energy Astrophysics and Cosmology from Space: NASA's Physics of the Cosmos Program

Mark Bautz

MIT

PCOS Program Analysis Group Chair

Special thanks to:
Ann Hornschemeier, NASA's GSFC
PCOS Program Chief Scientist

pcos.gsfc.nasa.gov

Where does Physics live at NASA?

Prioritization from Astro2010 Decadal Report

Astro2010 science themes map to the Astrophysics Division themes:

New Worlds		Exoplanet Exploration
Cosmic Dawn		Cosmic Origins
Physics of the Universe	→	Physics of the Cosmos

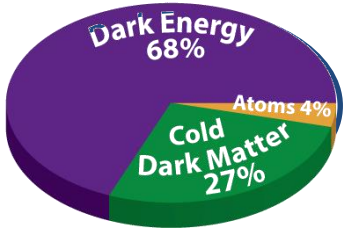
PCOS Science Objectives reflect the the highest priority Physics of the Universe science:

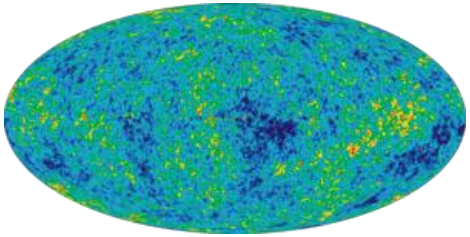
Dark Energy: Probe the nature of dark energy by studying the expansion rate of the universe and the growth of structure

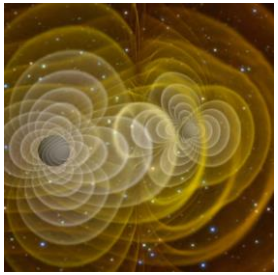
Theory of Inflation: Test the theory of inflation by measuring the polarization of the Cosmic Microwave Background.

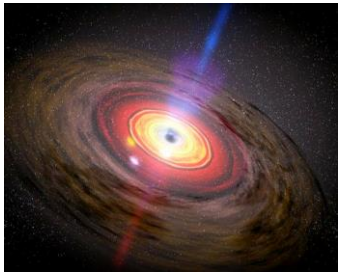
Black Holes & General Relativity: Probe the properties of black holes and test General Relativity using X-ray emission and gravitational waves.

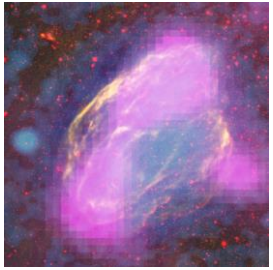
Physics of the Cosmos Science Objectives









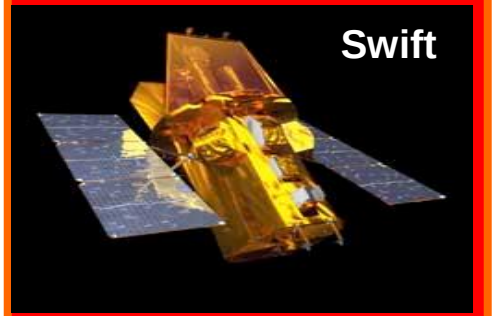


- Increase our knowledge of dark energy
- Precisely measure the cosmological parameters governing the evolution of the universe and test the inflation hypothesis of the Big Bang
- Test the validity of Einstein's General Theory of Relativity and investigate the nature of spacetime
- Understand the formation and growth of massive black holes and their role in the evolution of galaxies
- Explore the behavior of matter and energy in its most extreme environments

OPERATING MISSIONS

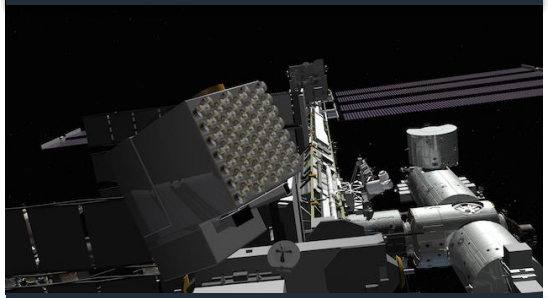
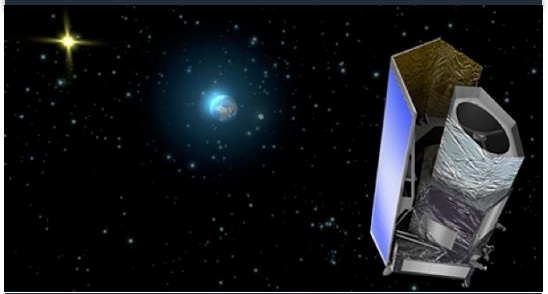
PCOS

PCOS-RELATED



The near future: PCOS missions in development

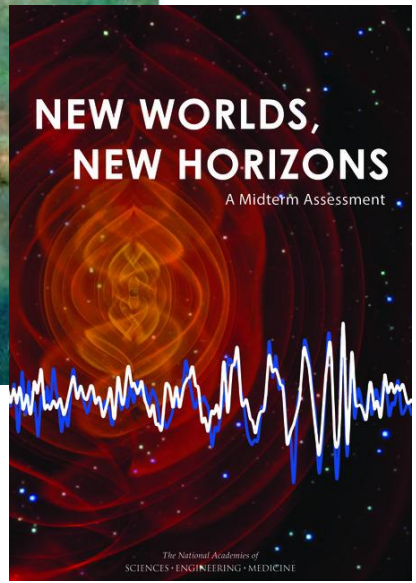
- **Three of seven projects in development during FY17 are in the PCOS portfolio: NICER, ISS-CREAM and Euclid. A fourth, IXPE, is PCOS-related.**

NICER 4/2017	CREAM 6/2017	Euclid 2020
NASA Mission	NASA Mission	ESA-led Mission
		
Neutron Star Interior Composition Explorer	Cosmic Ray Energetics And Mass	NASA is supplying the NISP Sensor Chip System (SCS)
XRSIG, R. Kraft	CosmicsIG, I. Moskalenko	CossIG, O. Doré

Physics of the Cosmos (PCOS):
Scientific and technical stewardship for future missions

Provide scientific and technical stewardship for decadal-survey recommended missions:

- **3 of the 6 highly-ranked medium and large-scale space-based priorities in NWNH fall within the PCOS science program:**
  - LISA (Gravitational Waves)
  - IXO (X-ray)
  - Inflation Probe (mid-scale)



2016 update includes:
- Response to Midterm Assessment
- Planning for 2020 Decadal Survey

Future Large Missions in PCOS: Athena, LISA and Lynx

- **ESA Cosmic Vision program (2016-2035):**
  - Athena/L2 (launch 2028) will be an X-ray observatory following the Hot and Energetic Universe theme
  - LISA/L3 (launch 2034) will be a gravitational wave observatory following the Gravitational Universe theme.
- **Athena is in Phase A (formulation) with NASA participation**
- **Large mission studies in PCOS (preparation for 2020 Decadal)**
  - NASA "L3 Study" recommended and will prepare case for NASA participation in LISA
  - Lynx (neé X-ray Surveyor) Study Team is preparing case for NASA development of a next-generation large X-ray Observatory (Lynx)
- **After this talk: John Conklin (LISA) & Ralph Kraft (Athena and Lynx)**

Athena: Advanced Telescope for High Energy Astrophysics

CURRENT STATUS

- Currently in 2-year Study Phase.
- NASA budgeting for a $100M-$150M hardware contribution, plus a U.S. GO program and a U.S. data center.
- NASA will contribute to both the X-IFU and the WFI instruments.
- NASA and ESA are discussing other possible NASA contributions to the observatory.
- NASA and U.S. community involvement in Athena Science Study Team (including its SWG) and Instruments facilitated via series of RFI and CAs.
- Athena team will expand at Adoption in 2020; NASA anticipates this will provide an opportunity to expand U.S. community involvement.

Second ESA Cosmic Vision Large mission

- L-class with NASA/JAXA participation
- Decadal Survey recommendation
- Large X-ray mirror, X-ray Integral Field Unit (XIFU) and Wide Field Imager (WFI) instruments

Launch Date: 2028

Breakthrough Capabilities:

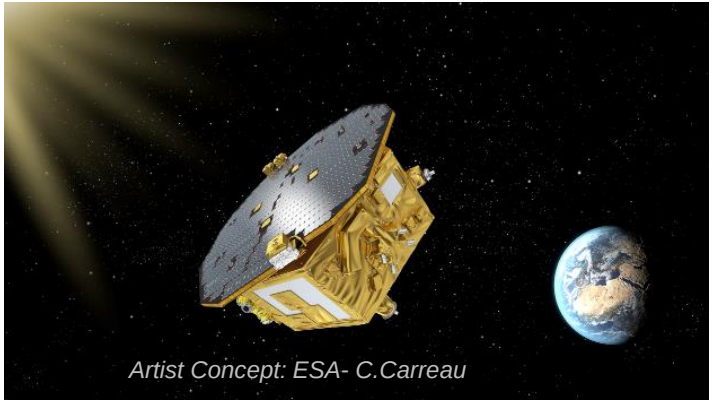
- High Throughput, High spectral resolution X-ray Astronomy, Wide FOV
- 10x Chandra area, 100x improved non-dispersive spectral resolution, 5x FOV.

Enabling Technologies: Silicon pore optics, 3000+ pixel μ-calorimeter (XIFU), large DEPFET array (WFI)

Science Objectives: The Hot and Energetic Universe: How does ordinary matter assemble into the large scale structures that we see today? How do black holes grow and shape the Universe?

www.the-athena-x-ray-observatory.eu

LISA Pathfinder ST-7/Disturbance Reduction System (DRS)

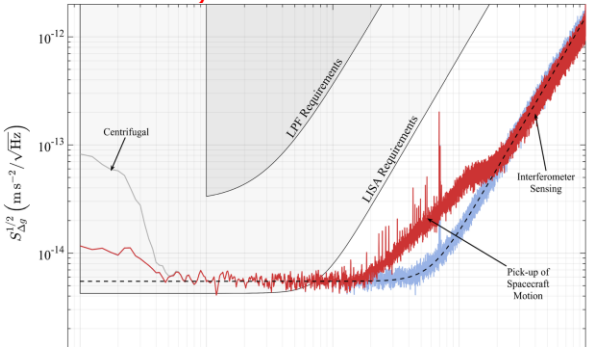


- ESA Mission with NASA Collaborating
- Project Category: 3 Risk Class: C
- DRS flies on the ESA LISA Pathfinder spacecraft
- Sun-Earth L1 halo orbit
- Drag-free satellite to offset solar pressure
- Payload delivery: July 2009
- Launched: December 3, 2015 GMT
- LPF prime mission: 7 months
- Data Analysis: 12 months

http://sci.esa.int/lisa-pathfinder/

CURRENT STATUS:

- LISA Pathfinder completed nominal ESA science operation on June 25, 2016
- NASA's DRS successfully completed its planned experiments and technology demonstration on December 7, 2016, ending the prime mission.
- Extended mission started December 8, 2016 and will continue into early 2017.
- LISA Pathfinder exceeded requirements and demonstrated critical technologies and systemic controls needed for a LISA-like gravitational wave observatory.



M. Armano et al., *Phys. Rev. Lett.* 116, 231101

L3 Study Team Interim Report

- L3 Study Team (D. Shoemaker, Chair) delivered Interim Report on options for NASA participation in ESA's L3 mission delivered June 20, 2016.
- The report identifies the major areas of interest for the US for gravitational wave technology development and provides an analysis of their respective benefits and limitations.

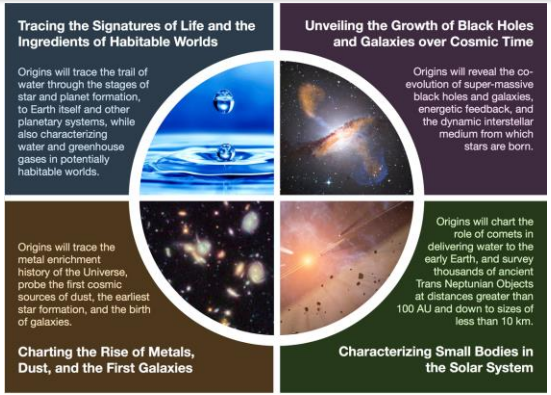
ATTENTION!

The L3 Study Team is holding an open meeting, immediately after APS, Tuesday afternoon and Wednesday morning. Details at link below.

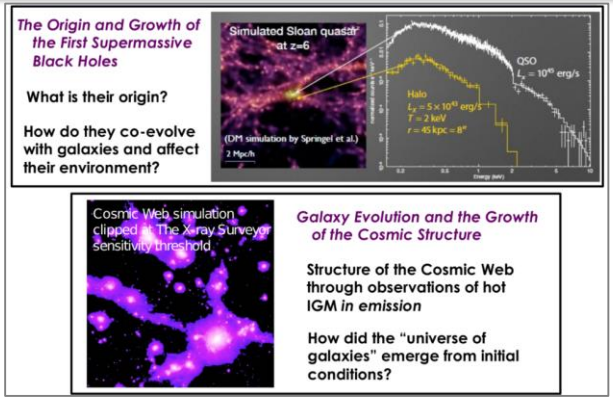
http://pcos.gsfc.nasa.gov/studies/L3/

NASA is studying four large mission concepts for consideration by the 2020 Decadal Survey

Origins Space Telescope



Lynx (PCOS)



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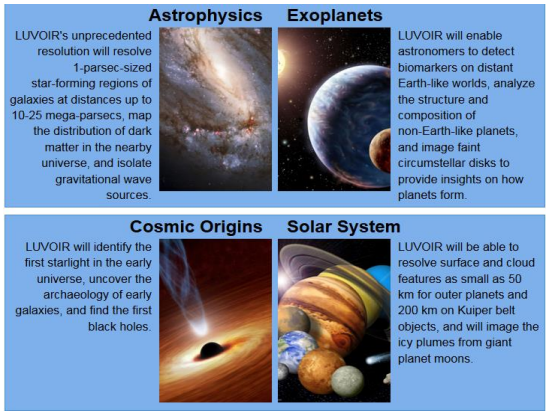

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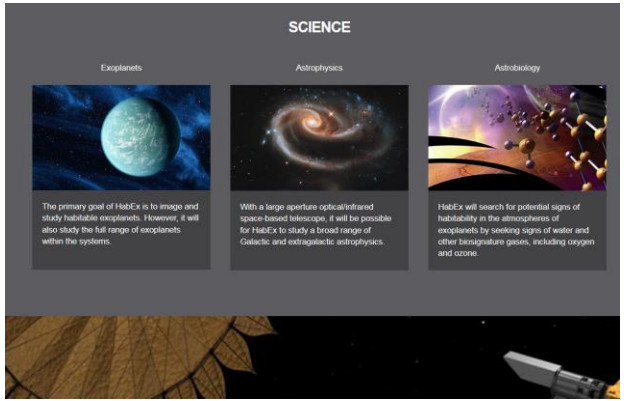


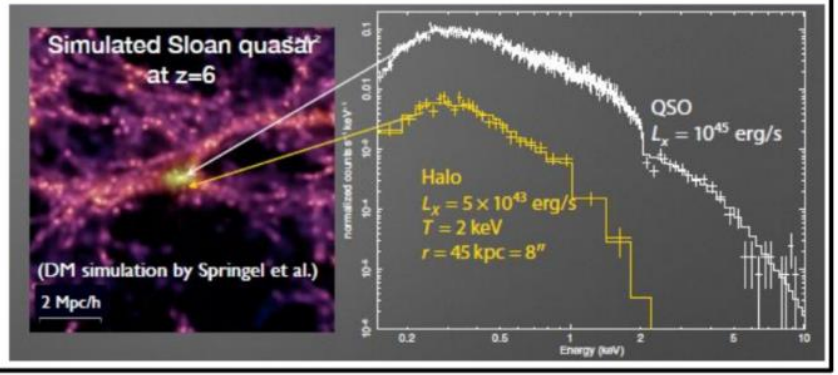
https://wwwastro.msfc.nasa.gov/lynx/

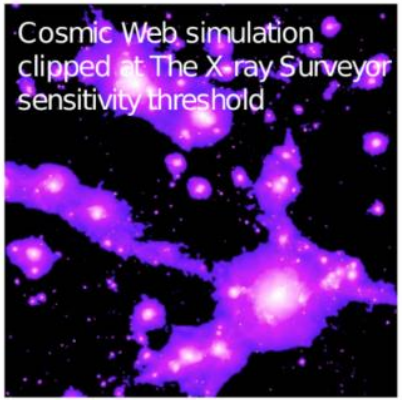
Lynx science drivers

The Origin and Growth of the First Supermassive Black Holes

What is their origin?

How do they co-evolve with galaxies and affect their environment?





Galaxy Evolution and the Growth of the Cosmic Structure

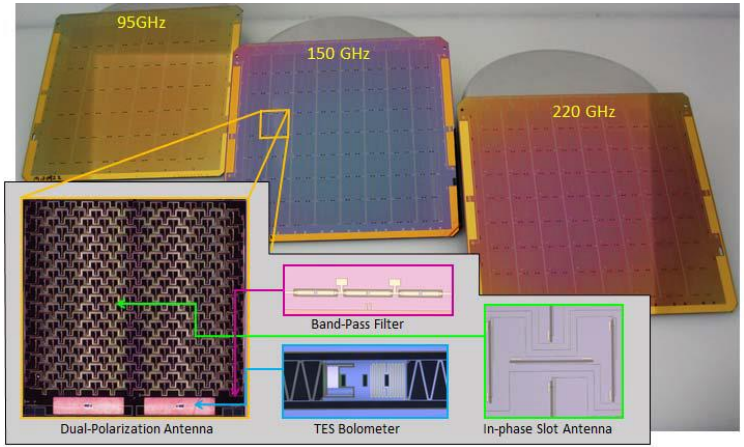
Structure of the Cosmic Web through observations of hot IGM *in emission*

How did the "universe of galaxies" emerge from initial conditions?

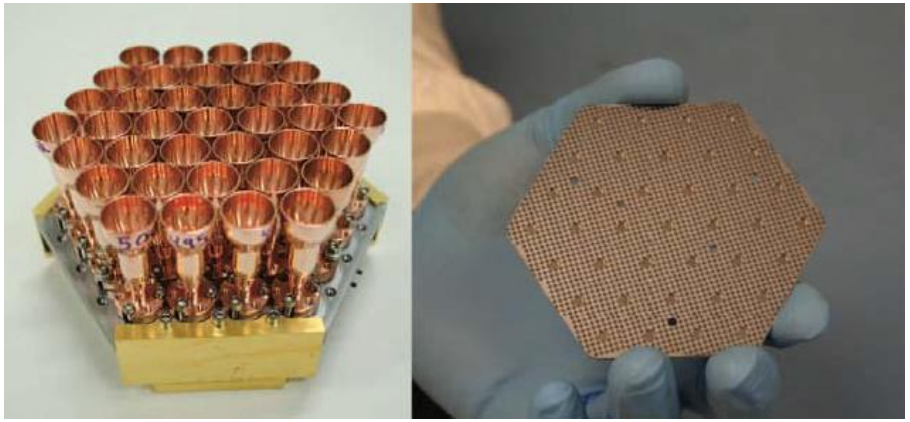
Lynx Study Leads: F. Ozel, A. Vikhlinin, J. Gaskin

Medium-size (Probe) Missions in PCOS: The Inflation Probe

- **Prime measurement: B-mode polarization of the Cosmic Microwave Background arising from primordial gravitational waves**
- **The 2nd ranked medium-scale mission in the 2010 decadal survey**
- **Main NASA-funded activities are via balloon & PCOS SAT programs, e.g..**



Planar Antenna-Coupled Superconducting Detectors for CMB Polarimetry. **P.I. J. Bock**

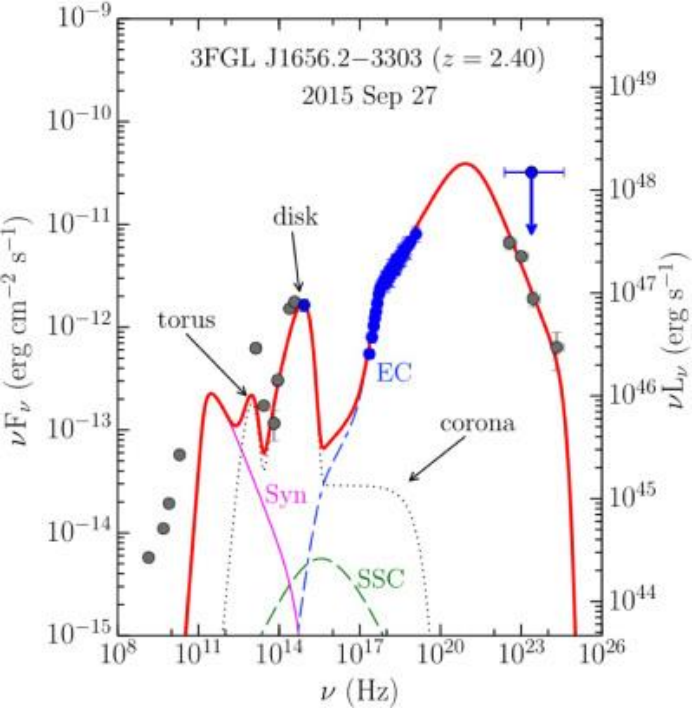


High-efficiency Feedhorn-Coupled TES-based Detectors for CMB Polarization. **P.I. Ed Wollack**

Probe Studies for the 2020 Decadal Survey

- **Astrophysics Probe: total lifecycle cost $400M to $1B**
  - NASA solicited mission concepts for funded studies in preparation for the 2020 Decadal Survey
  - 27 compliant study proposals received in all areas of astrophysics; Many of these are for PCOS concepts
- **Next Steps**
  - Selection of 5-8 concept studies expected in February 2017
  - Community workshop/interim reports due at the Winter 2018 AAS meeting
  - Final reports due to NASA in September 2018
- **NASA will submit the final reports and NASA cost assessments to the 2020 Decadal Survey**

Fermi-LAT discovery of the most distant gamma-ray blazars



- Distant blazars known to be exceptionally bright, with powerful jets and home to massive Black Holes
- X-ray and gamma-ray data suggest they are brightest in the 'MeV' band, just below the Fermi LAT energy range
- 5 new gamma-ray blazars by Fermi-LAT at z>3, two of which have $>10^9 M_{sun}$
- Enabled by improved performance following revamped data processing software
- Challenges models of supermassive black hole formation

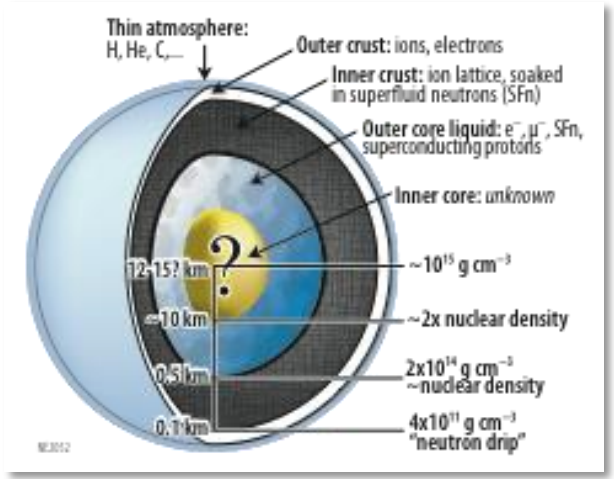
Fermi Guest Investigator program deadline Feb 24
see http://fermi.gsfc.nasa.gov/ssc

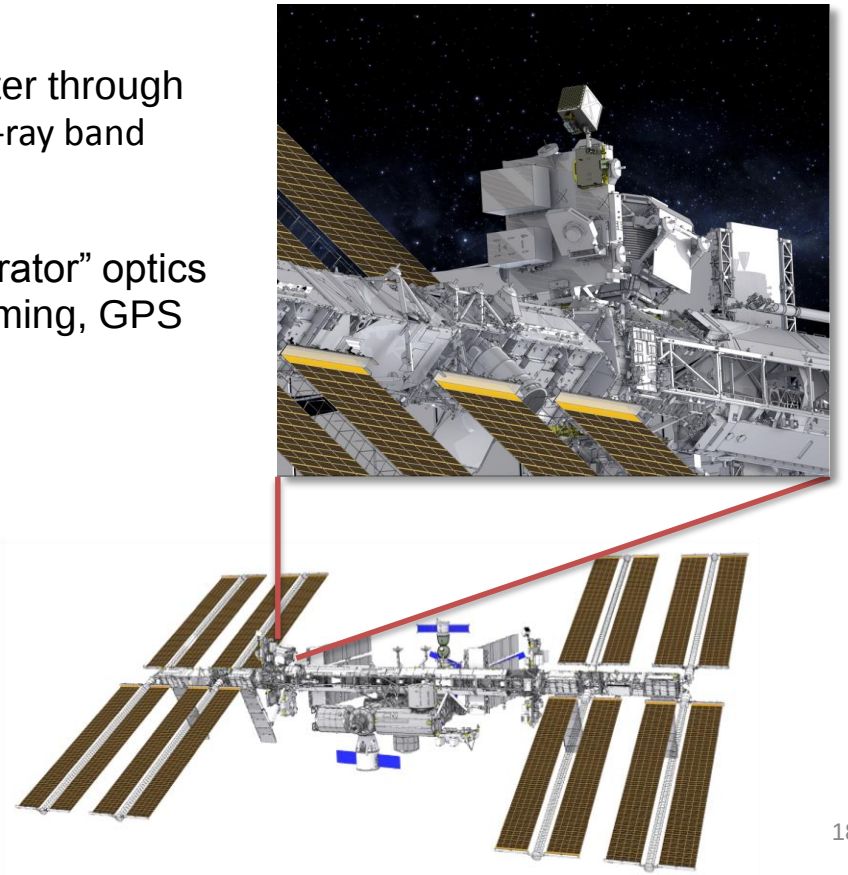
Suborbital and ISS activities in PCOS

- **Too many PCOS-related experiments on suborbital and International Space Station (ISS) platforms to cover in one talk!**
- **Two highlights going to the ISS: NICER and ISS-CREAM, launching in 2017**

NICER
(Neutron star Interior Composition ExploreR)

- *PI: Keith Gendreau, NASA GSFC*
- ***Science:*** Understanding ultra-dense matter through observations of neutron stars in the soft X-ray band
- ***Launch:*** April 2017, SpaceX-11 resupply
- ***Instrument:*** X-ray (0.2–12 keV) “concentrator” optics and silicon-drift detectors. Microsecond timing, GPS position & absolute time reference

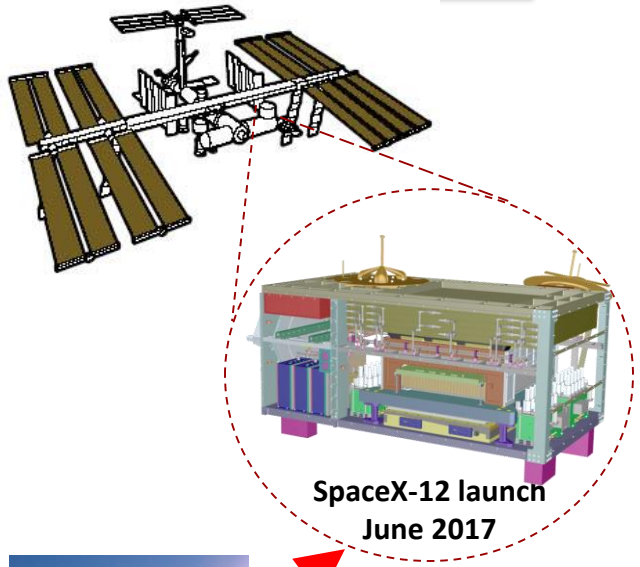




ISS-CREAM (CREAM for the ISS)

Cosmic Ray Energetics And Mass (CREAM)

- P.I.: Eun-suk Seo, Univ. of Maryland
- CREAM measures the energy spectra from 10^{12} to $>10^{15}$ eV over the elemental range from protons to iron.
- Building on the success of the balloon flights, the payload has been transformed for accommodation on the ISS (based on an APRA proposal).
- It extends the energy reach of direct measurements of cosmic rays to the highest energy possible to probe their origin, acceleration and propagation.



SpaceX-12 launch
June 2017

Increase the exposure by an order of magnitude

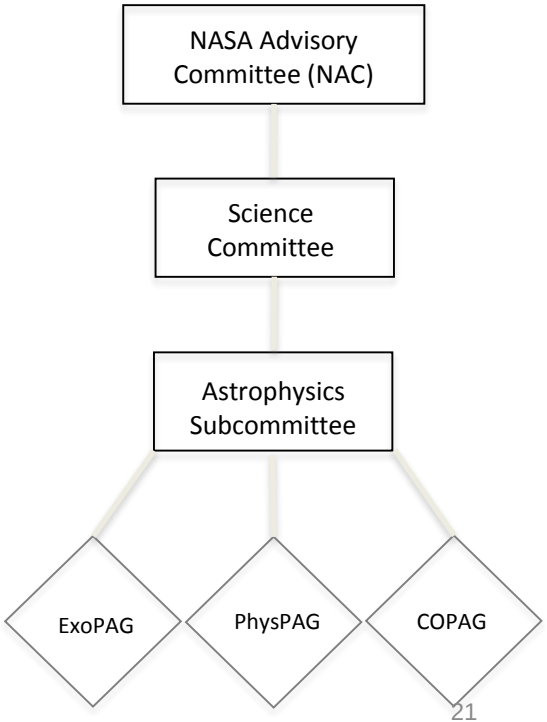
How can you interact with NASA’s Physics of the Cosmos program?

Program Analysis Groups (PAGs): Community Input to NASA Astrophysics

- Program Analysis Groups (PAGs) are open community groups
- Purpose of PAGS: NASA / community communication
- There are three NASA Astrophysics PAGS:
  - Physics of the Cosmos PAG (PhysPAG)
  - Cosmic Origins PAG (COPAG)
  - Exoplanets PAG (ExoPAG)
- The Physics of the Cosmos Program Analysis Group (PhysPAG) communicates with NASA about PCOS program science & goals
- PhysPAG has Six Science Interest Groups:
  - Cosmic Rays (CosmicSIG)
  - Cosmic Structure (CosSIG)
  - Gamma-ray Astrophysics (GAMMASIG)
  - Gravitational Waves (GWSIG)
  - Inflation Probe (IPSIG)
  - X-ray Astrophysics (XRSIG)
- **All are welcome to participate:**

pcos.gsfc.nasa.gov

Advisory Committees



PhysPAG Executive Committee Membership

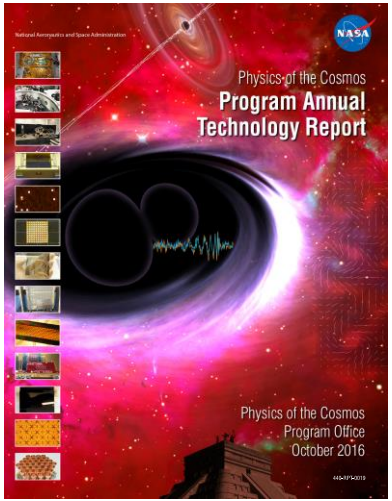
- **Six SIGs in operation for the Inflation Probe, Gamma Rays, Cosmic Rays, Gravitational Waves, X-rays & Cosmic Structure**

Name	Affiliation	Area of Expertise	Term Ends
M. Bautz (Chair)	MIT	X-ray astrophysics	Dec 2017
R. Bean	Cornell University	Dark energy	Dec 2017
J. Beatty	Ohio State University	Particle astrophysics	Dec 2019
J. Conklin (Vice Chair)	Univ. of Florida	Gravitational Waves	Dec 2017
O. Doré	JPL	Dark energy	Dec 2017
S. Guiriec	George Washington Univ.	Gamma-ray astrophysics	Dec 2019
K. Holley-Bockelmann	Vanderbilt University	Gravitational Waves	Dec 2019
R. Kraft	SAO	X-ray astrophysics	Dec 2018
H. Krawczynski	Washington University	Gamma-ray astrophysics	Dec 2017
A. Miller	Columbia University	CMB	Dec 2017
I. Moskalenko	Stanford University	Particle astrophysics	Dec 2018
J. Tomsick	UC Berkeley	X-ray and Gamm-ray astrophysics	Dec 2019
E. Wollack	NASA/GSFC	CMB	Dec 2017

PCOS community activities

- Encourage your finishing students and early-career postdocs to apply for the Einstein Fellows' program
  - Einstein Fellows hold their appointments at a Host Institution in the U.S. for research broadly related to PCOS science goals
- The PhysPAG provides input on technology needs that influences NASA priorities for technology development funding.
- These priorities are published in the PCOS Annual Technology Report (PATR).

Lia Corrales, 2016 Fellow



Keeping up with PCOS

http://pcos.gsfc.nasa.gov

- **View the latest newsletter.**
- **Sign up to the PCOS email list.**
- **Sign up to be included on SIG emails.**
- **Members of NASA PCOS Team include:**
  - At NASA GSFC:
    - Ann Hornschemeier
    - Terri Brandt
  - At NASA HQ:
    - Rita Sambruna
    - Dan Evans
    - Wilt Sanders

National Aeronautics and Space Administration

Physics of the Cosmos Newsletter

July 2016 Vol. 6 No. 1

Physics of the Cosmos Program Update

Peter Bertone, *PCOS Program Deputy Chief Scientist*
Ann Hornschemeier, *PCOS Program Chief Scientist*
Mansoor Ahmed, *PCOS Program Manager*

Welcome to this special edition newsletter devoted to suborbital projects related to high energy astrophysics and cosmology under the Physics of the Cosmos (PCOS) science themes. We highlighted suborbital projects in our 2014 PCOS newsletter and plan to do this approximately every 2 years or so given that for many areas in PCOS there is a great amount of activity going

Contents

NASA's Fermi Satellite Kicks Of a Blazar-detecting Bonanza

In April, 2015 NASA's Fermi Gamma-ray Space Telescope observed a flood of high-energy gamma rays from a blazar outburst, which helped two ground-based gamma-ray observatories detect some of the highest-energy light ever seen from a galaxy so distant. The observations provide a surprising look into the environment near a supermassive black hole at the galaxy's center and offer a glimpse into the state of the cosmos 7 billion years ago.

"When we looked at all the data from this event, from gamma rays to radio, we realized the measurements told us something we didn't expect about how the black hole produced this energy," said Jonathan Biteau at the Nuclear Physics Institute of Orsay, France.

Astronomers had assumed that light at different energies came from regions at different distances from the black hole. Gamma rays, the highest-energy form of light, were thought to be produced closest to the black hole. "Instead, the multiwavelength picture suggests that light at all wavelengths came from a single region located far away from the power source," Biteau explained.

The gamma rays came from a galaxy known as PKS 1441+25, a type of active galaxy called a blazar. At its heart lies a monster black hole with a mass estimated at 70 million times the sun's and a surrounding disk of hot gas and dust.

Black-hole-powered galaxies called blazars are the most common sources detected by NASA's Fermi Gamma-ray Space Telescope. As matter falls toward the supermassive black hole at the galaxy's center, some of it is accelerated outward at nearly the speed of light along jets pointed in opposite directions. When one of the jets happens to be aimed in the direction of Earth, as illustrated here, the galaxy appears especially bright and is classified as a blazar. Credits: M. Weiss/CfA

In April, PKS 1441+25 underwent a major eruption. Luigi Pacciani at the Italian National Institute for Astrophysics in Rome was leading a project to catch blazar flares in their earliest stages in collaboration with the Major Atmospheric Gamma-ray Imaging Cerenkov experiment (MAGIC), located on La Palma in the Canary Islands. Using public Fermi data, Pacciani discovered the outburst and immediately alerted the astronomical community. Fermi's Large Area Telescope revealed gamma rays up to 33 billion electron volts (GeV), reaching into the highest-energy part of the instrument's detection range. For comparison, visible light has energies between about 2 and 3 electron volts.

Read the full article: http://www.nasa.gov/feature/goddard/nasas-fermi-satellite-kicks-of -a-blazar-detecting-bonanza

PhysPAG SIG sessions later today!

- **J4 : Cosmic Ray Science Interest Group I**
  - 10:45am Room Virginia A
- **K4: Cosmic Ray Science Interest Group II**
  - 1:30pm, Room Virginia A
- **K5 : Gravitational Wave Science Interest Group Mini-Symposium**
  - 1:30pm Room Virginia B
- **K9 : Gamma-Ray Science Interest Group Mini-Symposium**
  - 1:30pm Room Roosevelt 1

- **Charts for this session and all three SIG sessions will be on the PCOS website starting tomorrow.**

THANK YOU

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pcos.gsfc.nasa.gov

(Sign up for email list at “PCOS News and Announcements tab)

THANK YOU

BACK-UP SLIDES